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14. ABSTRACT

This report results from a contract tasking A.F.Ioffe Physical-Technical Institute as follows: The contractor will investigate the relations between photoelectric and electric properties of several doped noncentrosymmetric crystals, mainly of iron doped lithium niobate crystals, LiNbO3:Fe, and their photorefractive properties. Photovoltaic effect, photo- and dark conductivity will be studied experimentally in parallel with studies of formation and other properties of holographic gratings in the samples of LiNbO3:Fe, which differ in the stoichiometry of the host (Li/Nb ratio), the concentrations of Fe ions, the Fe2+/Fe3+ ratios, and the concentrations of hydrogen. The experimental results and their theoretical analysis will allow the process of holographic grating formation in LiNbO3:Fe to be established on a microscopic level. The distribution of electric fields and charges in holographic gratings will be investigated spectroscopically and the microscopic structure of the Fe-centers dominant in photoelectric and photorefractive properties of LiNbO3:Fe crystals will be examined. Also, the photorefractive and photoelectric properties of strontium barium niobate, SrxBa1 xNb2O6 (SBN with x=0.61), will be studied. The proposed studies are to be conducted with the use of experimental facilities of the Solid State Optics Department of Ioffe Institute.

15. SUBJECT TERMS
EOARD, Holographic Devices, Non-linear Optical Materials , Photorefractive Materials

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CRDF Grant RPO-1385-ST-03
Final Scientific Report
20th Quarter (March 2008 - May 2008)

C o n t e n t s

1.a Objects and Directions of Study for the 20th Quarter

$Sr_xBa_{1-x}Nb_2O_6$ (SBN) is a very attractive material for optical data processing and storage devices. It is known that doping with rare earth ions can have a strong affect on photorefractive properties of the SBN. For example, doping with Ce was found to increase the photorefractive sensitivity in the visible region by two orders of magnitude in comparison with pure SBN crystals. Hence, regarding photorefractive applications of this material it is important to know optical properties and parameters of other possible rare earth impurity centers in the crystal lattice of SBN.

In this quarter we report on the study of the absorption spectra of different rare earth ions in $Sr_xBa_{1-x}Nb_2O_6$ crystal. The results of the study have been submitted to Physica Status Solidi.

1.b Results and Conclusions

The absorption spectra of Ce^{3+}, Nd^{3+}, Eu^{3+}, Tb^{3+}, Er^{3+}, Tm^{3+} and Yb^{3+} rare earth impurity ions incorporated in $Sr_xBa_{1-x}Nb_2O_6$ (SBN) crystals were studied in a wide spectral range from the visible to the far infrared. On the basis of the analysis of the Ce^{3+} absorption line shapes and their polarization properties, the conclusion was drawn about the incorporation of multiple Ce^{3+} centers mostly in the A1 position of the crystal lattice of SBN. From the observed temperature dependence of the Ce^{3+} absorption line broadening, the electron coupling strength (160 cm^{-1}) and effective phonon energy (300 cm^{-1}) were determined.

1.c Exhibits

Paper preprint:
R. Demirbilek, A.B. Kutsenko, R. Pankrath, and S.E. Kapphan. "Absorption Spectroscopy of Rare Earth Impurity Centers in $Sr_xBa_{1-x}Nb_2O_6$ Crystals". *physica status solidi*, to be published.

2.a Main results obtained in the course of the Project execution

In the frames of the CRDF Project № RPO-1385-ST-03, a complex study of the material properties and charge transport phenomena was carried out in a direct comparison with photorefractive properties for a number of the ferroelectric and virtual ferroelectric materials.

The following important results have been obtained:

EPR (Electron Paramagnetic Resonance) studies directly supported a simple optical method developed at WPAFB (in collaboration with Ioffe) to measure concentrations of Fe^{2+} and Fe^{3+} in $LiNbO_3$:Fe crystals;

strong effects of the growth methods and post-growth treatments of $LiNbO_3$ crystals were found on Fe centers – their concentrations and microstructures;

presence of different Fe centers in differently treated $LiNbO_3$ crystals was identified as a cause of very different efficiencies of TBC (Two Beam Coupling) in those samples;

with a goal to directly measure the electric fields in photorefraction gratings, Stark effect with novel manifestations caused by the repoling of the sample under the electric field was found on Fe centers in $LiNbO_3$:Fe;

by means of CEES (Combined Excitation - Emission Spectroscopy) technique, 14 nonequivalent positions of Eu^{3+} centers were resolved in the VTE samples of $LiNbO_3$:Eu;

EPR spectra, photocurrent excitation spectra, and dark conductivity were studied on $KNbO_3$:Fe crystals and compared with the results obtained at AFRL on these same samples through optical absorption and contra-directional two-beam coupling;

non-volatile holographic storage, based on the two-centre holographic recording has been tested in double doped strontium barium niobate ($Sr_xBa_{1-x}Nb_2O_6$:Ce:Cr);

three absorption bands in the far-infrared absorption spectra of $Sr_xBa_{1-x}Nb_2O_6$:Ce were attributed to the three nonequivalent positions of Ce^{3+} in SBN lattice;

strong optical alignment of Cu^{2+} and three Ni^{3+} related centers was found and studied in $KTaO_3$ crystals;

electric-field effects in $KTaO_3$ crystals were studied on the Ni related center.

These results have been reported in 14 presentations given at 11 International Conferences and published in 12 papers (see the lists below, Section 2.b).

2.b Declarations, disclaimers, and acknowledgments

The following papers and presentations given at the International Conferences acknowledge the support by CRDF, Grant RPO-1385-ST-03:

Papers:

1. С.А. Басун, А.Г. Раздобарин, Л.С. Сочава, D.R. Evans. "Оптическое выстраивание аксиальных центров Cu^{2+} в $KTaO_3$: спектральная зависимость эффекта". *Физика Твёрдого Тела*, 2004, т.**46**, №2, сс.253-258

2. S.A. Basun, A.G. Razdobarin, L.S. Sochava, D.R. Evans. "Optical alignment of Cu^{2+} axial centers in $KTaO_3$: spectral dependence of the effect". *Physics of the Solid State*, 2004, v. **46**, no. 2, pp. 258-264.

3. R. Demirbilek, A.B. Kutsenko, R. Pankrath, S.E. Kapphan. "Investigation of Far Infrared Transitions of Ce^{3+} in Congruent SBN Crystals". *Ferroelectrics*, 2004, v. **303**, no. 1, pp. 177-180.

4. R. Demirbilek, S.E. Kapphan, A.B. Kutsenko, R. Pankrath. "Investigation of Two-Center Holographic Recording in SBN:Ce:Cr and SBN:Mn:Fe". *physica status solidi (c)*, 2005, v. **2**, 653-656.

5. Л.С. Сочава, С.А. Басун, В.Э. Бурсиан, В.С. Вихнин, А.Г. Раздобарин, D.R. Evans, S.E. Kapphan. "Низкосимметричный парамагнитный центр в кристалле $KTaO_3$:Ni". *Физика Твёрдого Тела*, 2007, т.**49**, №.3, сс.443-445

6. L.S. Sochava, S.A. Basun, V.E. Bursian, V.S. Vikhnin, A.G. Razdobarin, D.R. Evans, S.E. Kapphan. "Low-symmetry paramagnetic center in a $KTaO_3$:Ni crystal". *Physics of the Solid State*, 2007, v. **49**, no. 3, pp. 460-462

7. Л.С. Сочава, С.А. Басун, В.Э. Бурсиан, А.Г. Раздобарин, D.R. Evans. "Электрополевые эффекты в спектре ЭПР низкоспинового центра Ni^{3+} в кристалле $KTaO_3$". *Физика Твёрдого Тела*, 2007, т.**49**, №.12, сс.2157-2160

8. L.S. Sochava, S.A. Basun, V.E. Bursian, A.G. Razdobarin, D.R. Evans. "Electric field effects in the EPR spectrum of low-spin Ni^{3+} centers in $KTaO_3$". *Physics of the Solid State*, 2007, v. **49**, no. 12, pp. 2262-2265

9. S.A. Basun, V.E. Bursian, A.A. Kaplyanskii, A.G. Razdobarin, L.S. Sochava, S. Kapphan, D.R. Evans. "V-Shaped Stark Effect in Stoichiometric Photorefractive $LiNbO_3$". In *Controlling Light with Light: Photorefractive Effects, Photosensitivity, Fiber Gratings, Photonic Materials and More* on CD-ROM (The Optical Society of America, Washington, DC, 2007), MB4. ISBN: 1-55752-848-9.

10. A. Kaplyanskii, S. Kapphan, A.B. Kutsenko, K. Polgar, A.P. Skvortsov. "Multiplicity of Europium Centers in Doped Stoichiometric Crystals of Lithium Niobate". *Technical Physics Letters*, 2007, v. **33**, no. 4, pp. 337–339.

11. S.A. Basun, V.E. Bursian, D.R. Evans, A.A. Kaplyanskii, A.G. Razdobarin, L.S. Sochava. "Ferroelectric-specific Stark effect in stoichiometric $LiNbO_3$:Fe at room temperature". *Physical Review Letters*, 2008, v.**100**, pp.057602-1 - .057602-4

12. R. Demirbilek, A.B. Kutsenko, R. Pankrath, S.E. Kapphan. "Absorption Spectroscopy of Rare Earth Impurity Centers in $Sr_xBa_{1-x}Nb_2O_6$ Crystals". *physica status solidi*, to be published.

International Conference Presentations:

1. S.A. Basun, A.G. Razdobarin, L.S. Sochava, V.E. Bursian. "Anisotropic photoionization as a universal mechanism of optical alignment of axial defect centers". 15-th International Conference of Defects in Insulating Materials, ICDIM-2004: Abstracts - Riga, Latvia, July 11-16, 2004. – p.9

2. S. Basun. "Spectroscopic properties of doped insulators: manifestations of the photo electron transfer between impurities and host". Invited lecture given at the IV International Stokes Summer School, Skreen, Ireland, June 18-22, 2004

3. S.A. Basun. "Manifestation of the photoinduced charge transfer in spectroscopy of doped insulating crystals". XII-th Feofilov symposium on spectroscopy of crystals activated by rare earth and transition metal ions: Abstracts - Ekaterinburg-Zarechnyi, Russia, September 22-25, 2004. – p.7

4. S. Basun, D.R. Evans, G. Cook, M. Saleh, J. Gibbson. "Contra-directional two beam coupling and direct measurements of the photovoltaic effect in $KNbO_3$:Fe". II International Workshop on Photorefraction, St. Petersburg (Florida), USA, July 7-9, 2004

5. S. Basun, V. Bursian, A. Razdobarin, L. Sochava, D. Evans, M. Saleh. "EPR and two-beam coupling results on VTE-treated and congruent $LiNbO_3$:Fe". II International Workshop on Photorefraction, St. Petersburg (Florida), USA, July 7-9, 2004

6. S. Basun, L.S. Sochava, V.E. Bursian, A.G. Razdobarin, D. Evans. "Stark effect on VTE-treated $LiNbO_3$:Fe". III International Workshop on Photorefraction, Charleston (South Carolina), USA, August 21-27, 2005

7. S. Basun, L.S. Sochava, V.E. Bursian, A.G. Razdobarin, D.R. Evans, J.L. Carns, M.A.Saleh, G. Cook. "Absorption of Fe in $LiNbO_3$: Optics and EPR". IV International Workshop on Photorefraction, Tampa (Florida), USA, August 21-27, 2006

8. S. Basun, L.S. Sochava, V.E. Bursian, A.G. Razdobarin, D.R. Evans, J.L. Carns, M.A.Saleh, G. Cook. "Stark effect and mobility of cations in $LiNbO_3$:Fe". IV International Workshop on Photorefraction, Tampa (Florida), USA, August 21-27, 2006

9. S.A. Basun, V.E. Bursian, A.A. Kaplyanskii, A.G. Razdobarin, L.S. Sochava, S.E. Kapphan, D.R. Evans. "Stark effect in EPR spectra of VTE $LiNbO_3$:Fe". XIII Feofilov symposium on spectroscopy of crystals doped by rare earth and transition metal ions: Abstracts - Irkutsk, Lake Baikal, Russia, July 9-13, 2007. – p.14

10. S.A. Basun, V.E. Bursian, A.A. Kaplyanskii, A.G. Razdobarin, L.S. Sochava, S.E. Kapphan, D.R. Evans. "V-Shaped Stark Effect in Stoichiometric Photorefractive $LiNbO_3$". Topical OSA Meeting "Controlling Light with Light": Abstracts - Squaw Valley, Lake Tahoe, California, USA, 14-16 October 2007. – p.MB4

11. S. Basun, L.S. Sochava, V.E. Bursian, A.G. Razdobarin, D.R. Evans. "Photoconversion of the Ni centers in $KTaO_3$". V International Workshop on Photorefraction, St. Augustine (Florida), USA, August 28-31, 2007

12. S. Basun, L.S. Sochava, V.E. Bursian, A.G. Razdobarin, D.R. Evans, G. Cook, M.A.Saleh. "EPR characterization of differently poled $KNbO_3$:Fe crystals". V International Workshop on Photorefraction, St. Augustine (Florida), USA, August 28-31, 2007

13. S. Basun, A.G. Razdobarin, L.S. Sochava, V.E. Bursian, D.R. Evans, G. Cook. "Conversion of Fe-centers under re-poling of $LiNbO_3$:Fe". VI International Workshop on Photorefraction, Hilton Head Island (South Caroline), USA, June 09-13, 2008

14. S. Basun, A.G. Razdobarin, L.S. Sochava, V.E. Bursian, D.R. Evans, G. Cook. "Anneaqling of $LiNbO_3$ in lithium carbonate powder". VI International Workshop on Photorefraction, Hilton Head Island (South Caroline), USA, June 09-13, 2008

(1) In accordance with Defense Federal Acquisition Regulation 252.227-7036, Declaration of Technical Data Conformity (Jan 1997), "The Contractor, Professor A.A. Kaplyanskii, hereby declares that, to the best of his knowledge and belief, the technical data delivered herewith under Contract No. FA8655-03-D-0001, DO 0006, is complete, accurate, and complies with all requirements of the contract.

DATE: 23 September, 2008

Name and Title of Authorized Official (Project Director):
Professor A.A. Kaplyanskii

(2) In accordance with the requirements in Federal Acquisition Regulation 52.227-11, Patent Rights-Retention by the Contractor, A.A. Kaplyanskii (Jun 1997),

"I certify that there were no subject inventions to declare as defined in FAR 52.227-11, during the performance of this order."

DATE: 23 September, 2008

Name and Title of Authorized Official (Project Director):
Professor A.A. Kaplyanskii

The referenced Federal Acquisition Regulations can be found at http://farsite.hill.af.mil or http://www.arnet.gov/far/